The Run IIb CDF and DØ Detector Upgrade Projects

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Fermilab

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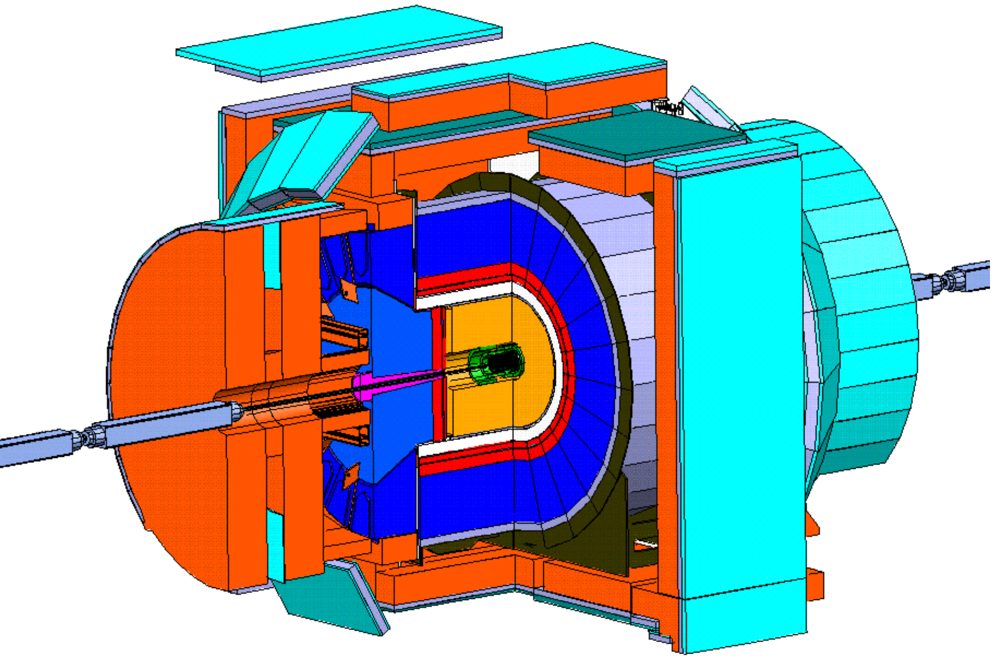
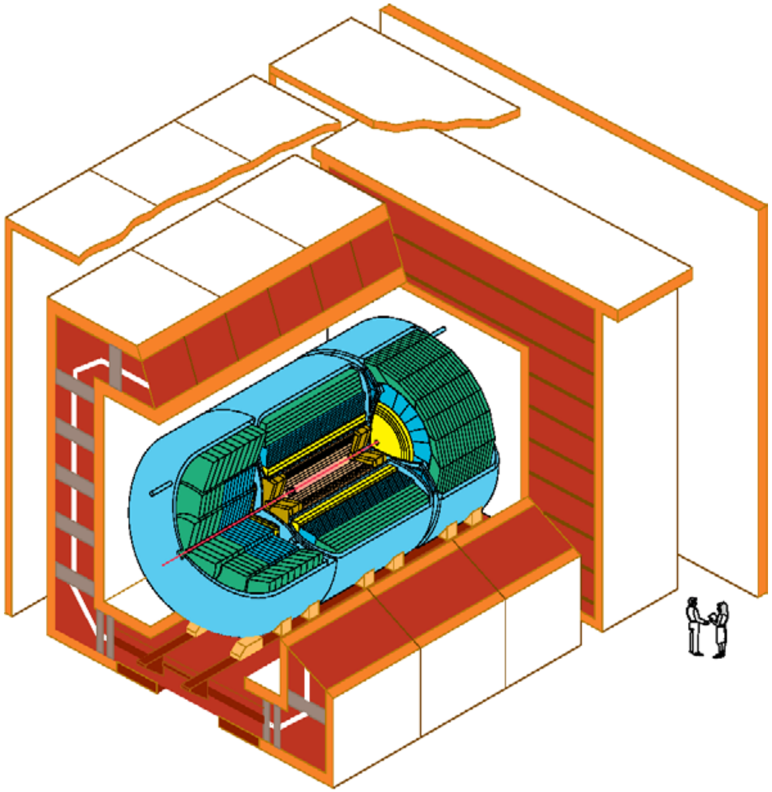
Collider Detectors



CDF Detector



DØ Detector

The two collider detectors complement each other
- Different strengths
- Makes the Tevatron program well suited for searches

Run IIb Motivation

- The collider experiments, CDF and DØ, were designed to run for 2 fb^{-1}.
  - Expected life is 3-4 fb^{-1}.
- Current laboratory plans extend Tevatron operation to 2009.
  - 8-15 fb^{-1} is possible
- The physics arguments are strong for extended operation beyond the Run IIa plan
  - We remain at the energy frontier until LHC physics
  - Much larger data sets from the experiments are possible.
- Run IIb projects allow an extension of CDF and DØ data collection up to the LHC era.

Run IIb Requirements

- Both experiments have problems that arise when faced with operation to 8-15 fb^{-1}.
  - The silicon tracking detectors will fail at integrated luminosities beyond 3-4 fb^{-1}.
- Data collection of 2-3 fb^{-1} $year^{-1}$ implies average luminosities of ~ 2-3 $10^{32} cm^{-2} s^{-1}$.
  - This rate implies ~5 interactions per crossing
  - Trigger rates will exceed the Run IIa design
  - Upgrades will be made
    - Improve trigger purity
    - Increase the data acquisition capacity

Run IIb Scope

- The design criteria for the Run IIb detector projects was focused
  - Operate to 15 fb^{-1}
  - Maintain the high P_T program
- Specific detector components selected for upgrade were chosen because they were critical to this goal.
- No significant functionality has been added.
- Both detector upgrade projects have a baseline.
- Completion by May, 2006

Silicon Lifetime

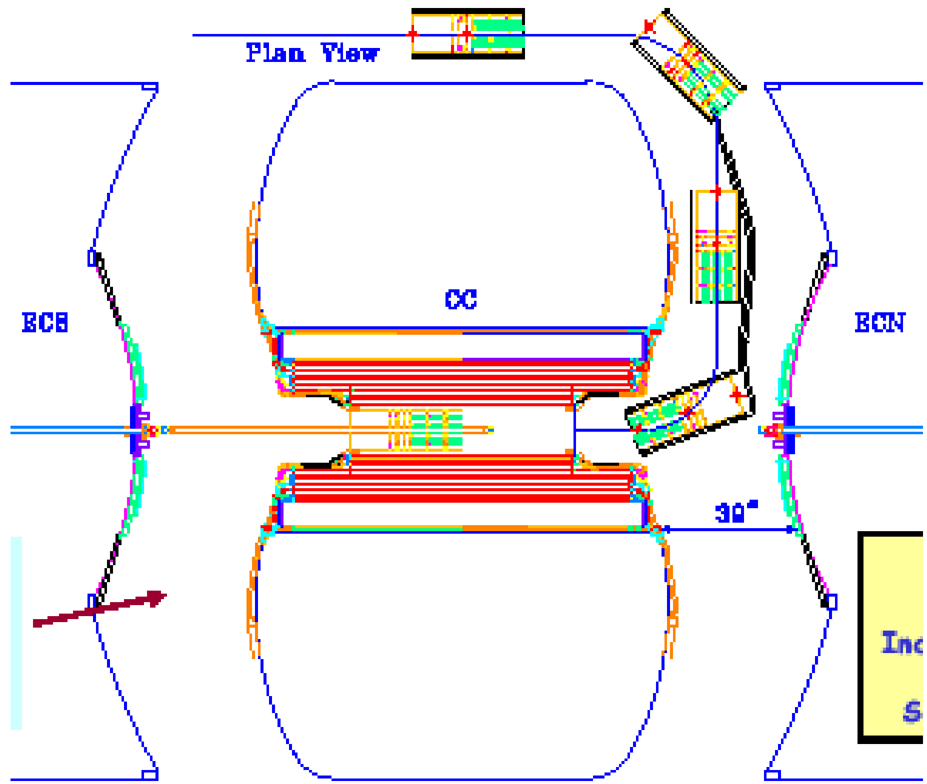
- Run I at CDF experience has taught us the expected particle fluence, as a function of radius and luminosity.
- Run II measurements have confirmed this function.
- CDF expects the safe life of its detector to be
  - 4.3 fb^{-1} for layer 0
    - included in the trigger
  - 5.7 fb^{-1} for the port cards
  - 7.4 fb^{-1} for layer 00 (innermost)
- DØ studies have combined beam tests and simulation.
- Leakage current increases seen in Run II seem consistent with expectations.
- The predicted impact on the detector is
  - 3.6 fb^{-1} - loss of efficiency
  - 4.9 fb^{-1} - inner layer is useless
- Uncertainties in these estimates are ~50%.

Silicon Replacement

- Both collaborations have reached the same conclusion concerning silicon aging
  - The entire inner detector must be replaced for Run IIb.
- Partial replacement scenarios have been rejected
  - Radial clearances available in the current detectors limit the options (new layers, single sided sensors, etc.)
  - There is considerable technical risk to disassembly
    - Fragile, glued parts were not designed to disassemble
  - Many parts used in the current detector are obsolete
    - SVX2, SVX3, DOIMs, double sided detectors,

Silicon Installation

- Furthermore, the installation of new silicon detectors forces a long shutdown.
- DØ will install "in place"
  - Estimated at 7 months
- Partial replacement would add a lengthy disassembly-reassembly step at the silicon facility.

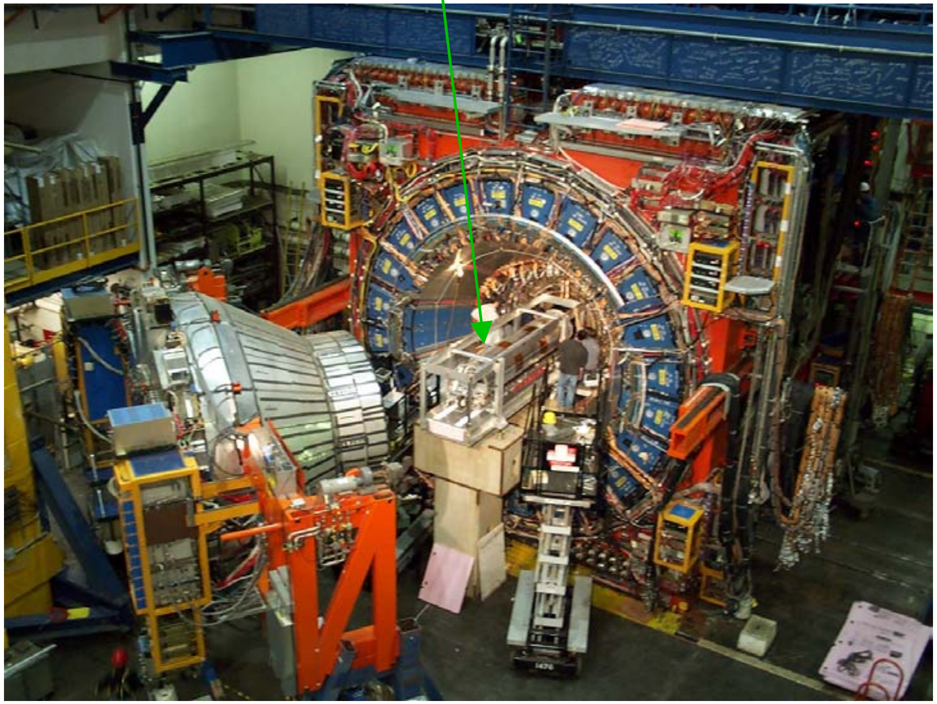


Plan view of DØ silicon installation

Silicon Installation

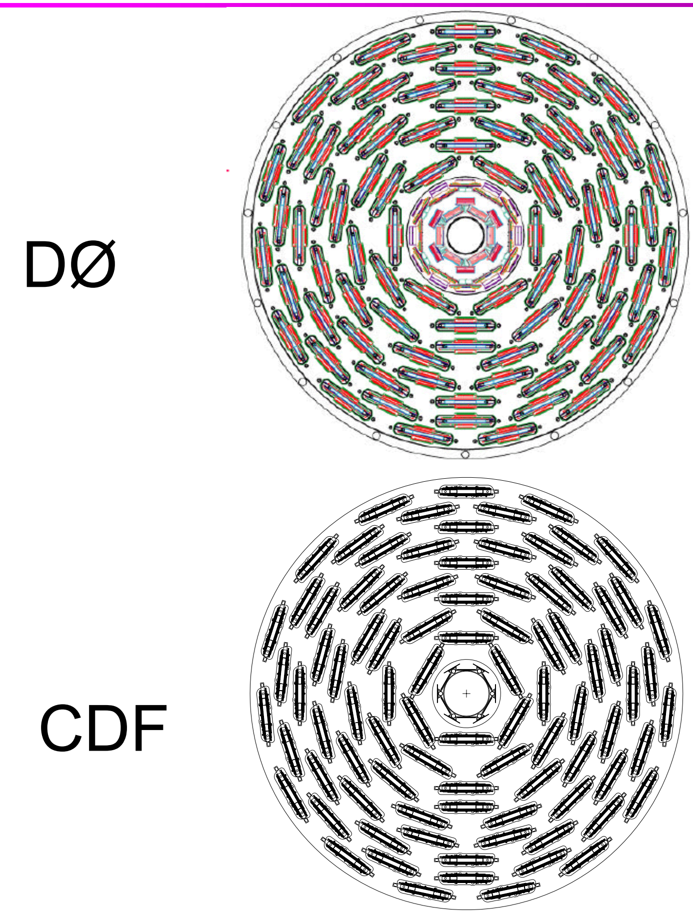
- Reuse of the ISL forces CDF to roll out.
  - Total installation estimated at 8 months.
- Partial replacement of SVX II would extend a shutdown by 6-12 additional months.
- Consequently, partial replacement is not considered viable.
  - Technical review of the projects concurred (Dec., 2001).

ISL and SVXII positioned for installation (Jan. 2001)



Silicon Replacement

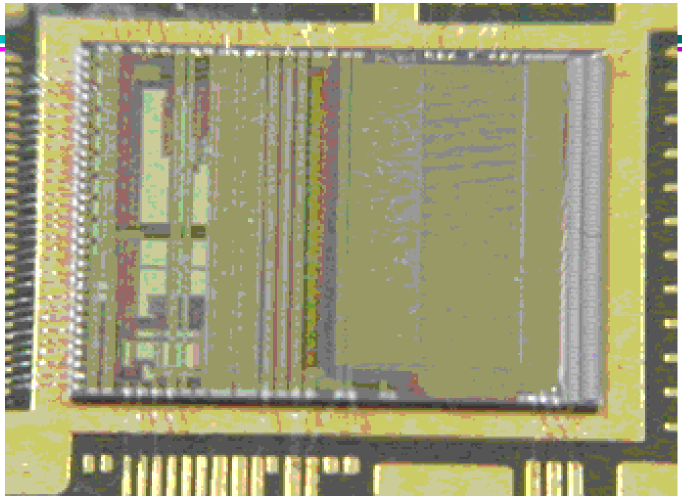
- The two collaborations have very similar silicon replacement designs
- Stave structures built of single sided sensors.
  - Fewer varieties of parts compared to Run IIa
- Joint effort has produced a single readout chip, similar mechanical designs and sensors.

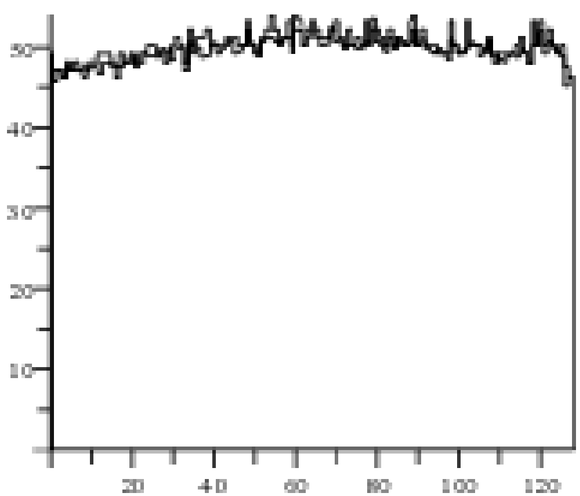


Transverse view of the Run IIb silicon trackers (same scale)

SVX4 chip

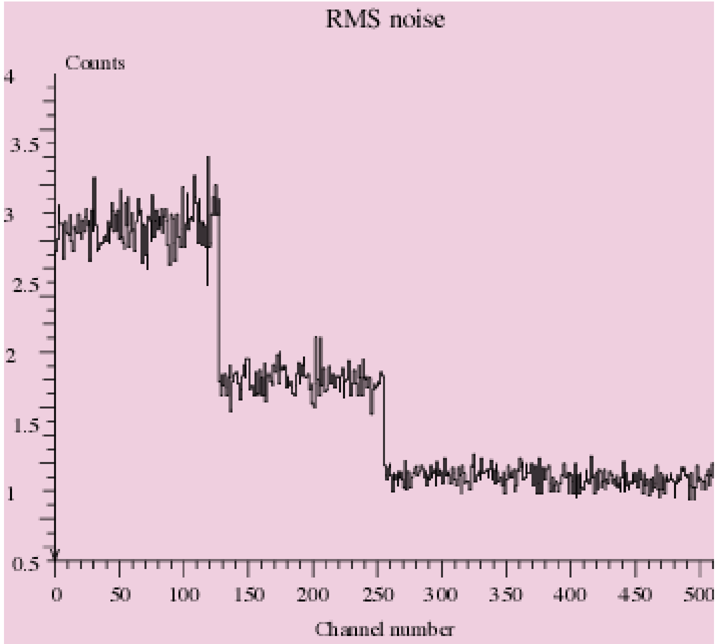
- 1st full prototype
  - submitted - April ’02 received June ‘02
  - Tested at LBL and FNAL
  - No major problems found
  - Corrections for bow and channel to channel variation – fixed in new chip
  - Yield looks very good, ~85%
  - Radiation tests showed no problems
- Next submission is in progress
  - Could be the final version

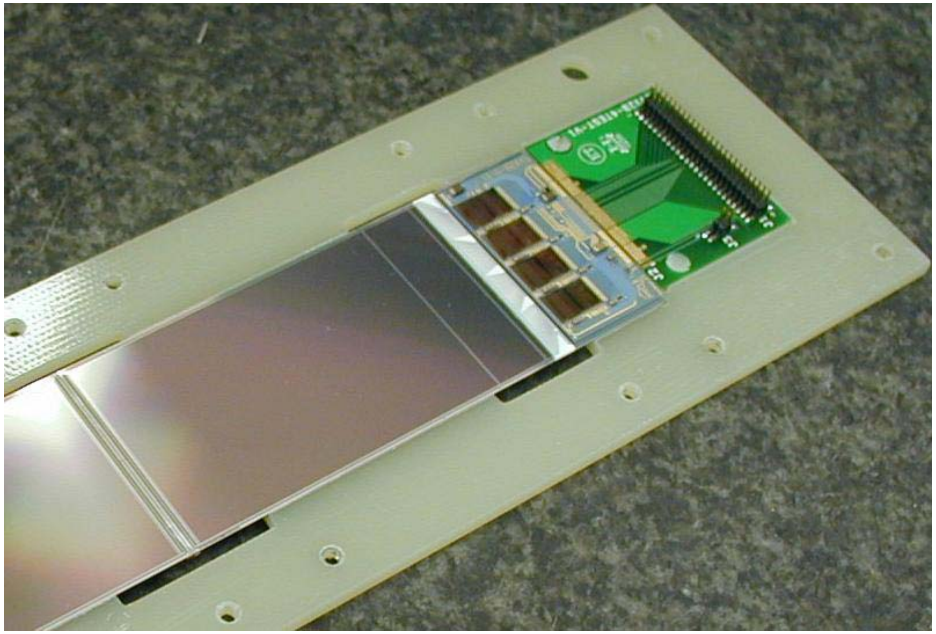




CDF Modules

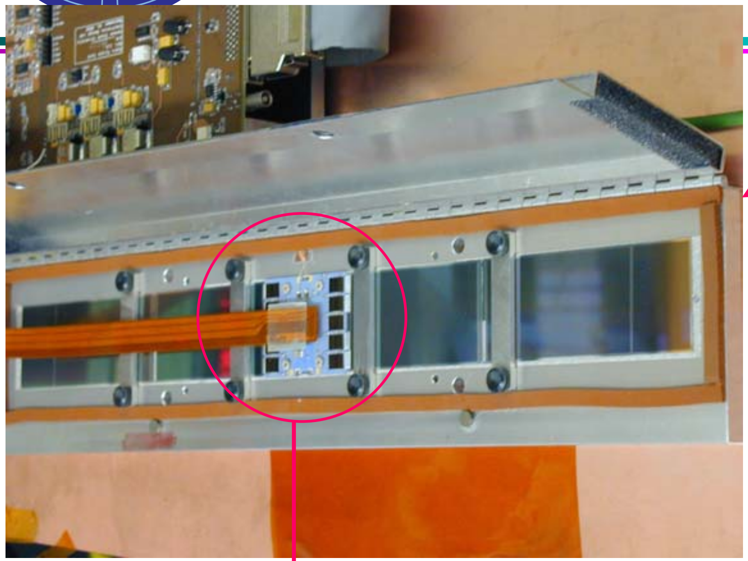
- Ten modules fully assembled
- Hybrids work with No problems!
- Module tests at LBL in progress, FNAL (FCC) with full DAQ

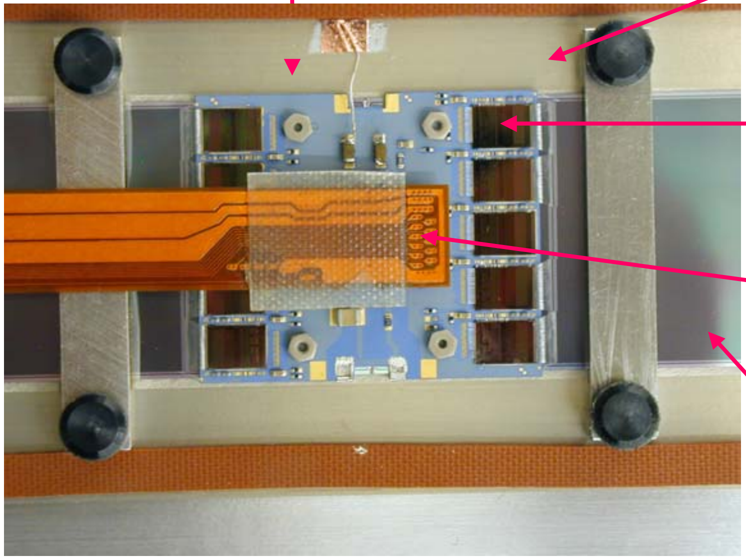




← Noise with 0, 1, and 2 sensors connected to the readout

DØ Modules

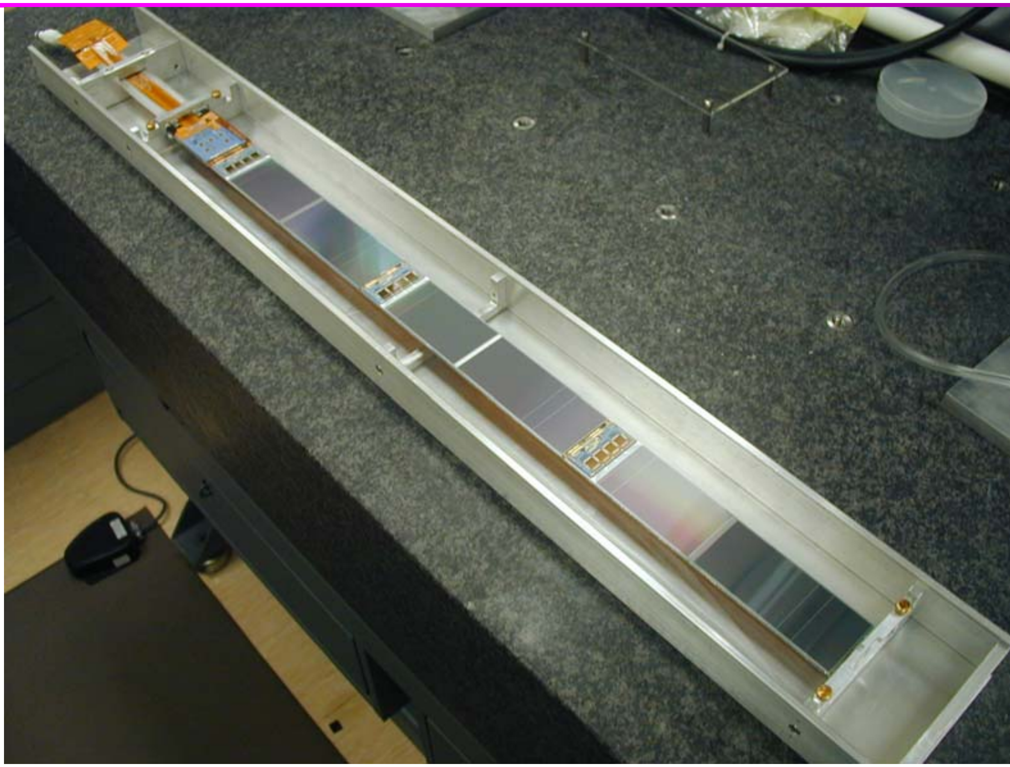




- First outer layer electrical-grade ("20/20") prototypes fabricated
- Two types: axial & stereo readout
- Each are 12 sensors long ~100 mm in length
- Stereo angle obtained by rotating sensors
- Testing underway

Electrical Stave Testing

- Prototype tests have been done on
  - SVX4 chips
  - Modules (sensors with hybrids and SVX4)
  - Full staves
    - Readout with the full DAQ
- Results have been good
- Prototypes are very successful, and close to production quality.



CDF Electrical Stave Prototype

DØ Prototype Mechanical Stave

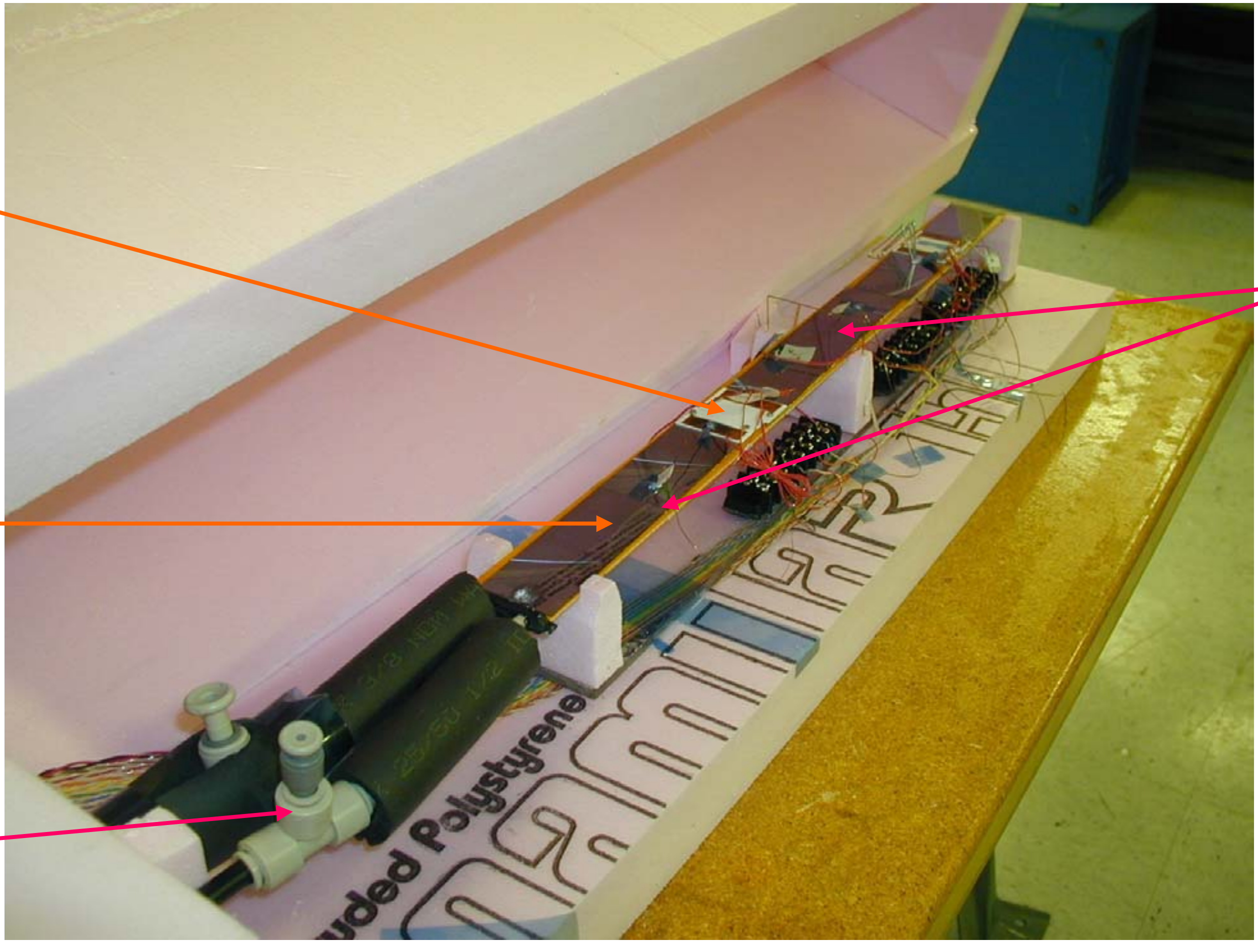
Prototype mechanical stave being thermally tested at SiDet

Dec 18 '02 integration milestone met

Aluminum-ceramic hybrid (dummy)

Stereo silicon, axial mounted underneath

Input cooling channel



10/10 (upper) 20/20 (lower) mechanical modules, concatenated

Trigger Upgrades

- The DAQ/Trigger upgrades planned are driven exclusively by the Run IIb trigger and data acquisition needs to carry out our high-p_T physics programs.
- Our current level of understanding is based upon Run I data and early Run IIa data
  - ~1-2 interactions per crossing
- We are extrapolating to Run IIb
  - ~5 interactions per crossing
- Both experiments have allowed for a trigger rate "headroom" of a factor of 2.

DØ Trigger Upgrade

System	Problems	Solutions
Cal	1) Trigger on $\Delta\eta\times\Delta\phi$=0.2×0.2 TTs ⇒ slow turn-on curve 2) Slow signal rise ⇒ trigger on wrong crossing	• Clustering • Digital Filter
Track	1) Rates sensitive to occupancy 2) Limited match to calorimeter	• Narrower Track Roads • Improve Cal-Track Match
Muon	No Additional Changes Needed!	• Requires Track Trigger

Trigger	Example Physics Channels	L1 Rate (kHz) (no upgrade)	L1 Rate (kHz) (with upgrade)
EM (1 EM TT > 10 GeV)	$W \to e\nu$ $WH \to e\nu jj$	1.3	0.7
Di-EM (1 EM TT > 7 GeV, 2 EM TT > 5 GeV)	$Z \to ee$ $ZH \to eejj$	0.5	0.1
Muon (muon p_T > 11 GeV + CFT Track)	$W \to \mu\nu$ $WH \to \mu\nu jj$	6	0.4
Di-Muons (2 muons p_T > 3 GeV + CFT Tracks)	$Z\to \mu\mu, J/\Psi \to \mu\mu$ $ZH \to \mu\mu jj$	0.4	< 0.1
Electron + Jets (1 EM TT > 7 GeV, 2 Had TT > 5 GeV)	$WH \to e\nu$+jets $tt \to e\nu$+jets	0.8	0.2
Muon + Jet (muon p_T > 3 GeV, 1 Had TT > 5 GeV)	$WH \to \mu\nu$+jets $tt \to \mu\nu$+jets	< 0.1	< 0.1
Jet+MET (2 TT > 5 GeV, Missing E_T> 10 GeV)	$ZH \to \nu\bar{\nu}b\bar{b}$	2.1	0.8
Muon + EM (muons p_T > 3 GeV+ CFT track + 1 EM TT > 5 GeV)	$H \to WW, ZZ$	< 0.1	< 0.1
Single Isolated Track (1 Isolated CFT track, p_T > 10 GeV)	$H\to \tau\tau, W \to \mu\nu$	17	1.0
Di-Track (1 isolated tracks p_T > 10 GeV, 2 tracks p_T > 5 GeV, 1 matched with EM energy)	$H \to \tau\tau$	0.6	<0.1

Level 1 systems

Core Run IIb trigger menu, simulated at 2E32, 396 ns

Total output rate with (without) L1 trigger upgrade = 3.2 (~30) kHz

Available L1 bandwidth budget: 5 kHz

Run IIb Triggers (CDF)

trigger path	σ_{L1}(nb)	σ_{L2} (nb)	σ_{L3} (nb)
High E_T electron	1,500	170	30
Plug electron + missing E_T	771	55	10
High P_T muon (CMUP)	1,773	200	8
High P_T muon (CMX)	1,773	200	8
2 high pT *b*-jets	10,840	200	10
missing E_T + 2jets	163	126	13
jets	6,500	42	12
missing E_T	overlap	163	3
Photons	overlap	50	15
$J/\psi \to \mu^+\mu^-$	850	38	10
High P_T jets	19,000	60	17
hadronic top	overlap	50	5
di-τ	5,000	50	4
missing E_T+τ	overlap	50	4
High E_T photons	13,500	110	21
dileptons, trileptons	1,000	190	45
total	**59,200**	**1904**	**215**
rate @4E32	**25kHz**	**750Hz**	**85Hz**
rejection factor	**~100**	**~33**	**~9**

Trigger Upgrades

- The two experiments have very similar issues with respect to the Run IIb operating conditions
  - Trigger rate limits at Level 1 (DØ) and Level 2 (CDF)
    - Current trigger systems will limit physics acceptance at Run IIb luminosities
  - Quickly rising fake rates due to high occupancy events
    - Track triggers, crucial for lepton triggers, suffer with occupancy
  - New silicon systems force replacement of silicon vertex triggers to accommodate the new geometries.

Rate limits

- CDF predicts a bottleneck in data acquisition for Run IIb
- Two systems have maximum throughput of ~300 Hz (need 750 Hz)
  - TDCs used for the drift chamber
  - Event builder – assembles data from various sources, and feed to Level 3
- Both will be replaced for Run IIb

- DØ plans to improve the quality of its Level 1 triggers
  - Calorimeter energy thresholds will be sharpened with an upgraded system
  - Granularity improvements will be made
    - Track trigger
    - Track-calorimeter matching
- These upgrades will allow tighter triggering, reducing the fakes and rate.

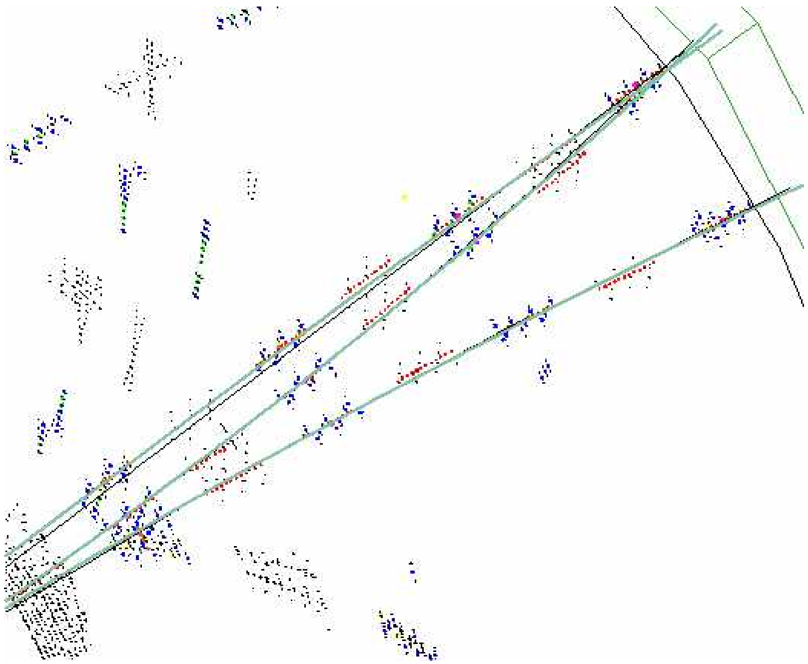
Track Triggers

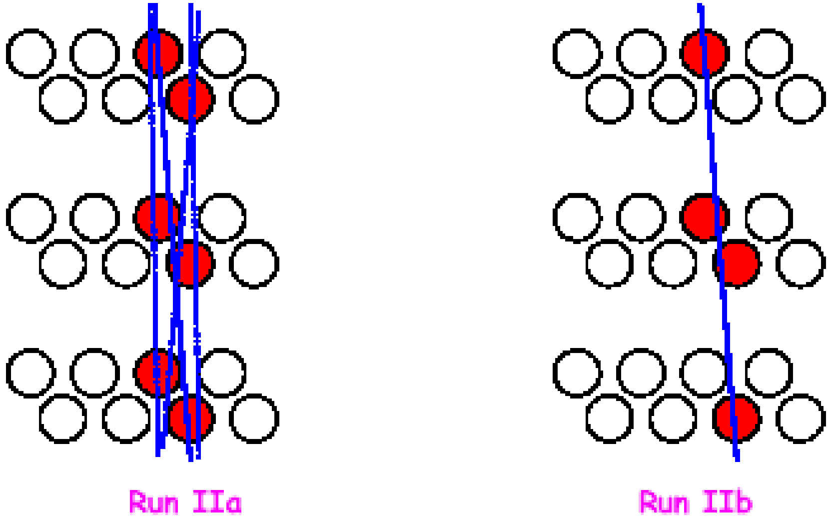
- High occupancy events will produce a rapid rise in the fake rate of track triggers for both experiments.
- For Run IIb, both groups will be increasing the granularity used at the trigger level, to combat the fake rate due to Run IIb occupancy.

- CDF’s trigger forms a crude track by binning the drift times, and matching against acceptable patterns
  - Run IIb upgrade will improve the resolution on the time binning used.

- DØ’s track trigger matches fiber doublet patterns to find track candidates.
  - Run IIb upgrade will switch to single fibers.

Track Granularity





DØ will go from using "doublets"
to single fibers in the tracking trigger

CDF will go from 2 time bins
Per crossing to 6 at the trigger level

Level 2 Processors

- Both experiments began Run II with Level 2 processors based on the (now obsolete) Alpha processor (DEC).

- CDF will replace Level 2
- New system based on
  - Modern FPGAs
  - PC based processor
- System will have flexible I/O, and is expandable

- DØ has L2βeta upgrade processors in prototype already.
- More are needed for Run IIb, for increased processing power.

CDF Funding Required

Cost (AY $K)	2002	2003	2004	2005	2006	Totals
Silicon	$ -	$ 2,865	$ 7,226	$ 7,165	$ 877	$ 18,134
Calorimeter	$ -	$ 785	$ 521	$ 16	$ -	$ 1,322
DAQ/Trigger	$ -	$ 749	$ 1,407	$ 3,635	$ -	$ 5,791
Administration	$ -	$ 420	$ 505	$ 516	$ 236	$ 1,677
Total Equ. Cost	$ -	$ 4,818	$ 9,659	$ 11,333	$ 1,113	$ 26,923
R&D Cost	$ 1,802	$ 1,477	$ 182	$ -	$ -	$ 3,460
Total Project Cos	$ 1,802	$ 6,295	$ 9,841	$ 11,333	$ 1,113	$ 30,383
Funding (AY $K)						
DOE - Equip. Tot	$ 3,500	$ 3,469	8,396	8,509	1,113	$ 24,987
DOE - R&D	$ 1,670	$ 480	$ -	$ -	$ -	$ 2,150
Japan	$ 235	$ 867	$ 1,081	$ 10	$ -	$ 2,193
Italy	$ 65	$ 351	$ 261	$ -	$ -	$ 676
University base	$ 24	$ 225	$ 103	$ 26	$ -	$ 377
Total Funding	$ 5,494	$ 5,392	$ 9,841	$ 8,544	$ 1,113	$ 30,383

- Costs include G&A and Contingency
- All costs/funds are in AY $K

DØ Funding Required

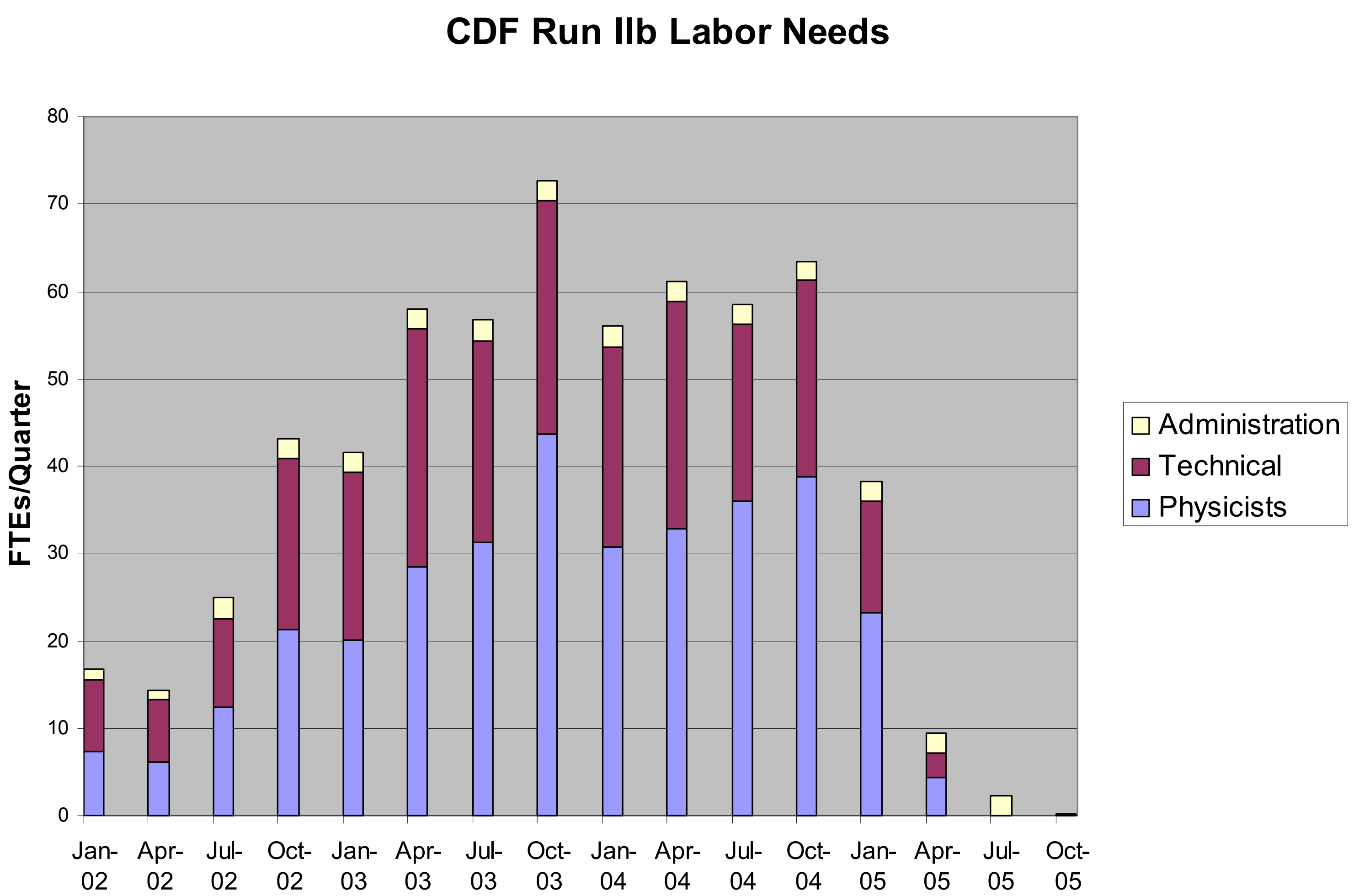
Includes G&A, contingency, & escalation

Funding need broken out by source

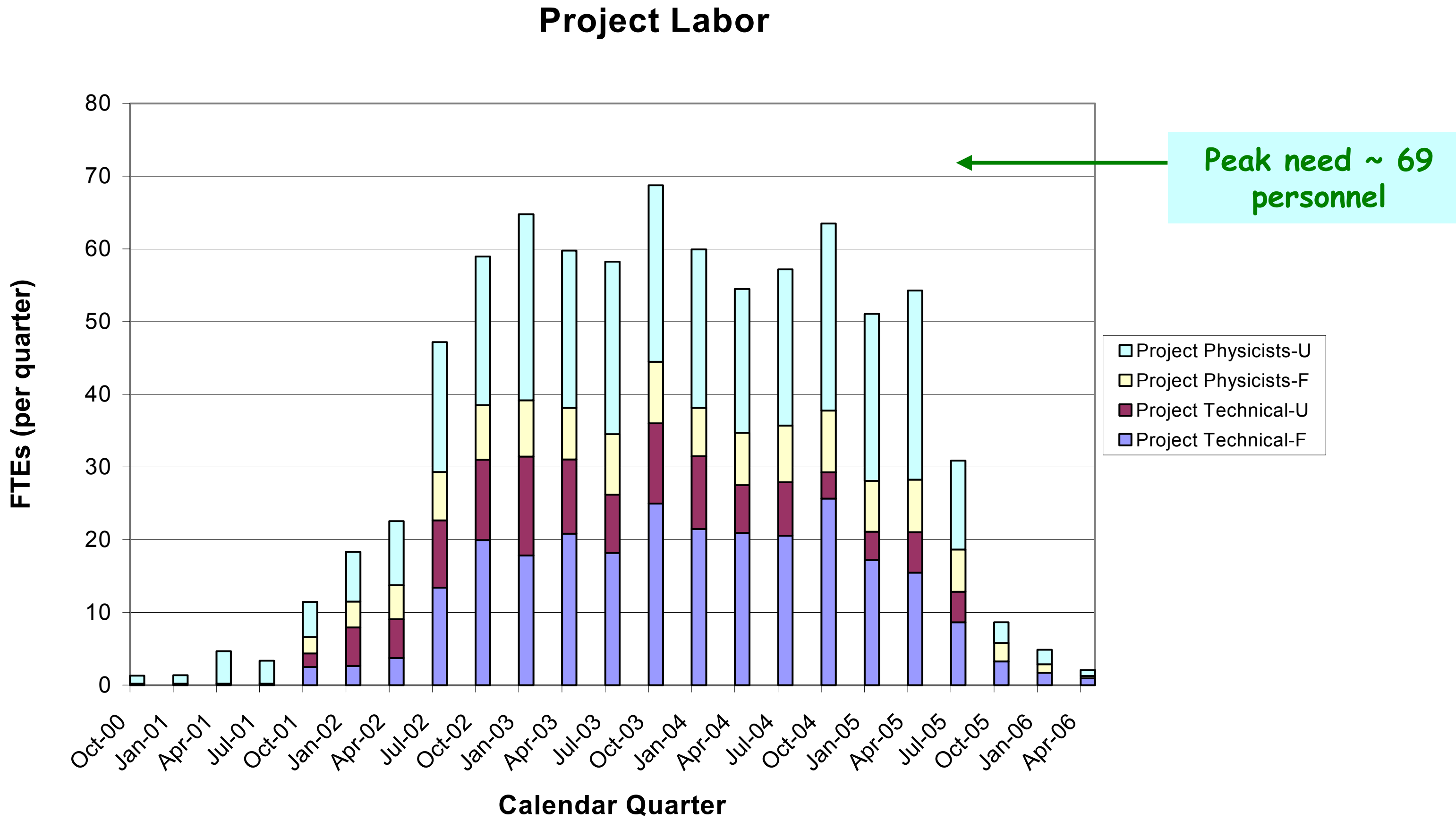
TPC, Obligation Profile In AY k$	FY01	FY02	FY03	FY04	FY05	FY06	TOTAL
Silicon (incl. Cont + G&A)	17	1326	4860	7165	3443	230	17040
Trigger (incl. Cont + G&A)	0	468	1363	946	1630	56	4462
Online (incl. Cont + G&A)	0	0	84	407	499	404	1393
Administration (incl. Cont + G&A)	0	0	343	499	516	471	1829
Total (excl. R&D)	17	1794	6650	9016	6088	1160	24724
R&D (incl. Cont + G&A)	0	1360	2519	0	0	0	3880
Total Project Cost	17	3154	9169	9016	6088	1160	28604
DOE M&S	0	0	4025	4160	2507	367	11060
DOE SWF	0	0	1045	2999	2325	617	6986
DOE G&A	0	0	631	1038	730	176	2575
TOTAL DOE EQ	0	0	5701	8197	5563	1160	20621
DOE M&S R&D	0	649	926	0	0	0	1575
DOE SWF R&D	0	464	1171	0	0	0	1635
DOE G&A R&D	0	248	422	0	0	0	670
TOTAL DOE R&D	0	1360	2519	0	0	0	3880
In Kind - Foreign	0	258	201	90	49	0	599
In Kind - MRI silicon	17	1326	495	631	0	0	2469
In Kind - MRI trigger	0	0	112	57	430	0	599
In Kind - US base	0	210	141	39	47	0	437
Total In-Kind contributions	17	1794	948	819	526	0	4104
Forward Funding			0			0	
Total Project Cost	17	3154	9169	9016	6088	1160	28604

Contingency on DOE Equipment Portion = 46%

Labor Required



DØ Total Project Labor



Total required to deliver silicon and trigger+online projects, divided into Fermilab and university components

Project Status

- In addition to the PAC, the Run IIb Detector Upgrade Projects have been reviewed by
  - Technical Review – Dec, 2001 (J. Pilcher)
  - Director's Cost and Schedule Review - Apr. and Aug, 2002 (E. Temple)
  - Baseline Readiness Review – Sep., 2002 (D. Lehman)
  - External Independent Review – Nov., 2002 (Jupiter Corp.)
- Critical Decisions 1, 2, and 3a were granted in Dec, 2002 by the Office of Science
  - Completed by AEP signoff by Undersecretary Card in Feb, 2003

Project Status

- CD-3a allows us to spend equipment money for project construction through FY 2003.
- Several significant procurements are in process
  - Second SVX4 readout chip submitted
  - Silicon Sensors for the outer layers
  - Preproduction Hybrids for the outer layers
- The projects are moving ahead with construction.

Summary

- We have developed a well focused program to upgrade CDF and DØ for the Run IIb era.
- These projects will maintain the high P_T physics program at the Tevatron until the LHC era begins.
- The projects have been extensively reviewed.
- The technical choices, cost, and schedule have been endorsed by a variety of reviewers.
- Construction has begun.